Statistique Canada

Structural Analysis Division

Division de l'Analyse Structurelle

Space Heating Scenarios for Ontario:

A Demonstration of the Statistics Canada Household Model

Working Paper
78-12-20

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1. Introduction

This paper describes the analytical and simulation capabilities of the currently implemented version of the 'Household Model' developed by the Structural Analysis Division, Statistics Canada. The 'Household Model', as described in 'A Design Framework for Long Term Energy - Economic Analysis of Dwelling Related Demand' (1), is a simulation framework and related data base of the Canadian housing stocks, residential construction and end use energy consumption in the residential sector. The purpose of the model is to provide an analytical tool for evaluating a variety of residential energy conservation strategies including insulation retrofitting and the introduction of new building standards, the possibilities for fuel substitution afforded by equipment retrofitting, and the impact of new technologies for space conditioning with respect to impacts on residential energy requirements and construction materials over time.

The simulation results for Ontario that are presented in the paper are for demonstration purposes only and do not constitute a forecast. The choice of Ontario was arbitrary; similar calculations can be performed for other provinces, for Canada as a whole, and for selected subprovincial regions.

At the time of preparation of this paper, the population and household formation block at the national level, the housing

1. Introduction

This paper describes the analytical and simulation capabilities of the prototype represented version of the "Economic Model" developed by the Structural Analysis Division, Statistics Canada. The "economic model", as described in "A Design Framework for Long Term Energy - Economic Analysis of Dwelling Related Energy" [1], is a simulation framework and related data base of the Canadian housing stocks, residential construction and end use energy consumption in the residential sector. The purpose of the model is to provide an analytical tool for evaluating a variety of residential energy conservation strategies including insulation retrofitting and the introduction of new building standards, the possibilities for fuel substitution afforded by equipment retrofitting, and the impact of new technologies for space conditioning with respect to impacts on residential energy requirements and construction materials over time.

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At the time of preparation of this paper, the population and household formation blocks at the national level, the housing

stock block, and the space heating part of the space conditioning block are implemented. Therefore simulation results are limited to these areas.

2. Overview of Model Structure

An overview of the model structure is depicted in Figure 2.0. The model consists of five blocks:

1. A population and household formation block which takes fertility, mortality, migration and headship rates and calculates the population by age and sex and the number of household units.

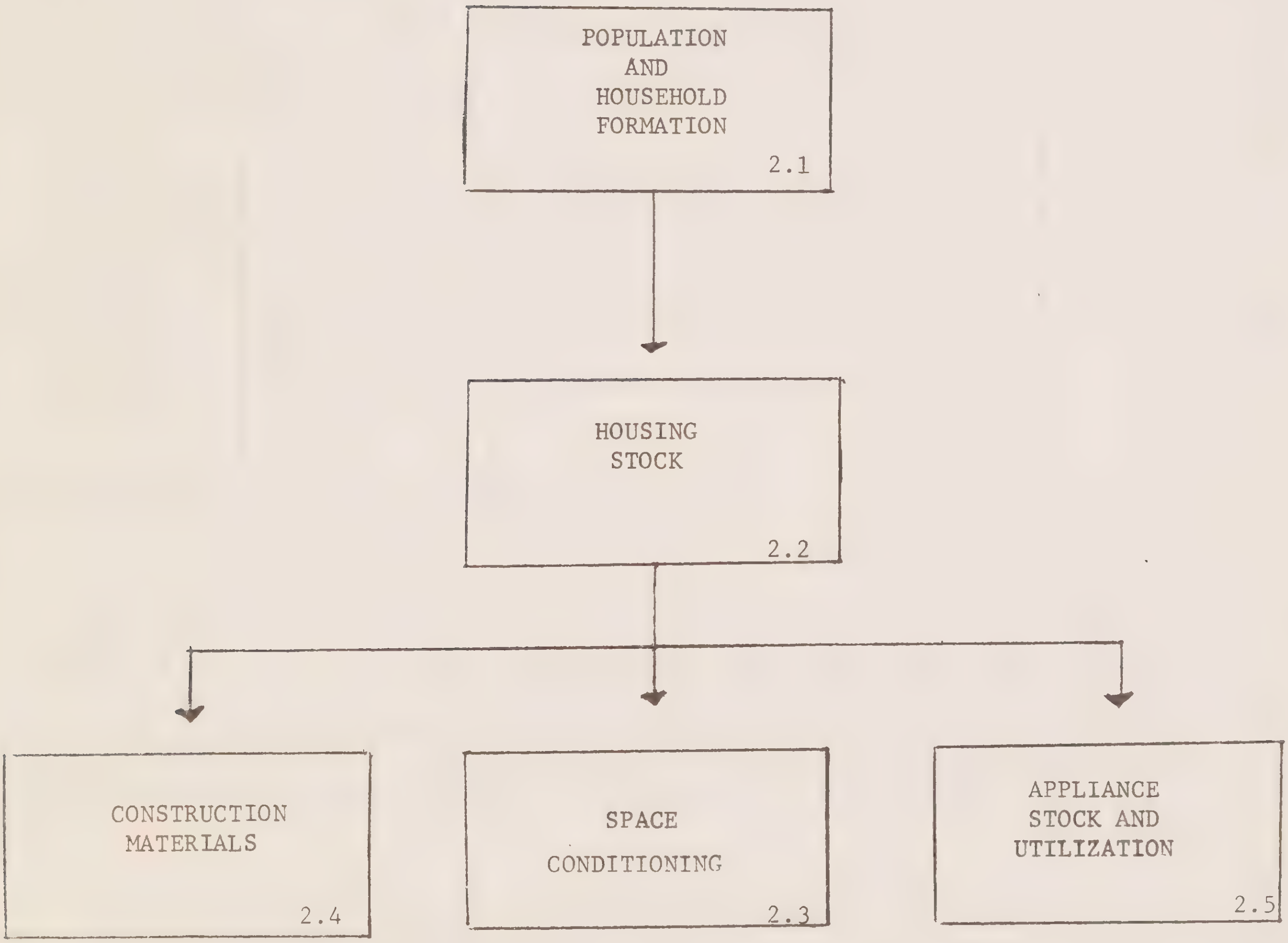
2. A housing stock formation block which keeps track of the stock of dwelling units stratified by a number of characteristics including dwelling type, period of construction, thermal characteristics, and heating equipment type.

3. A space conditioning block which calculates the amount of energy required to provide space heat and space cooling.

4. A construction materials block which calculates the quantity of labour and materials required for the

Figure 2.0

RESIDENTIAL STOCK AND ENERGY MODEL OVERVIEW.



construction of new units.

5. An appliance stock and utilization block which keeps track of the number of appliances by type of appliance including those for hot water heating, cooking, refrigeration, and home entertainment and which calculates the amount of energy required for the utilization of appliances.

The model is a single region model in that it performs calculations for a single region at a time. However, the region is specified by the user who may choose Canada as a whole, individual provinces, or selected sub-provincial regions.

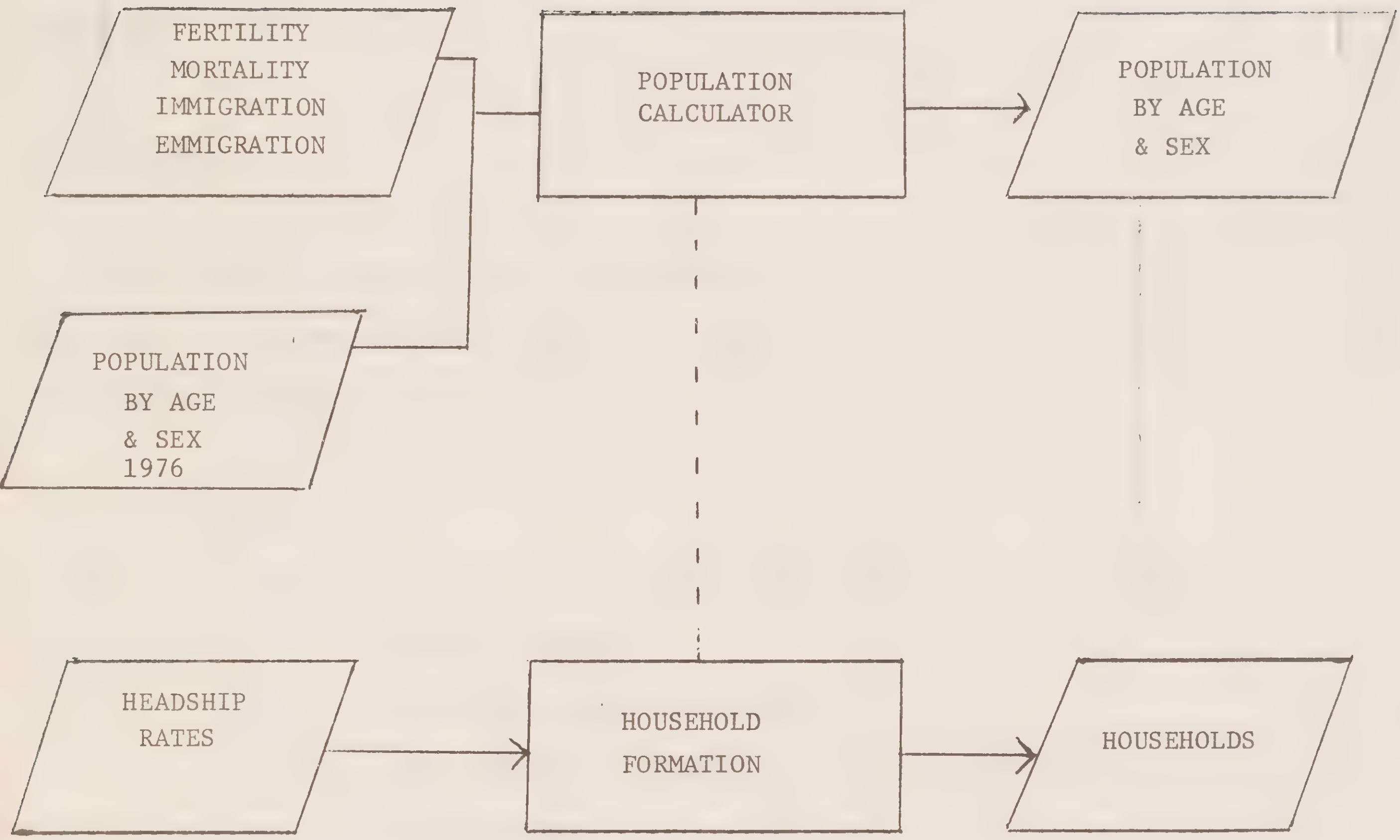
2.1 Population and Household Formation

The population and household formation block has been implemented at the national level only; this block was developed as a part of the Statistics Canada Long Term Simulation Model. A description of it may be found in the LTSM documentation.

For purposes of the simulations presented in this paper, the household projections developed by CMHC were used. The demographic assumptions are clearly explained in the CMHC Housing Requirements Model documentation.[2]

Figure 2.1

POPULATION AND HOUSEHOLD
FORMATION



2.2 Housing Stock Formation Block

There are two components to the housing stock formation model. One which traces the evolution of the base stock and the other that accounts for new construction during the projection periods.

Base Stock

The base housing stock is stratified by type of dwelling, period of construction, heating equipment class, and thermal characteristics.

Housing type

I= 1 = single detached dwellings (this includes mobile homes)

2 = semi-detached and duplex

3 = row houses and single attached houses

4 = apartments

Period of construction

J= 1 = built in 1920 and before

2 = built between 1921 and 1945

3 = built between 1946 and 1950

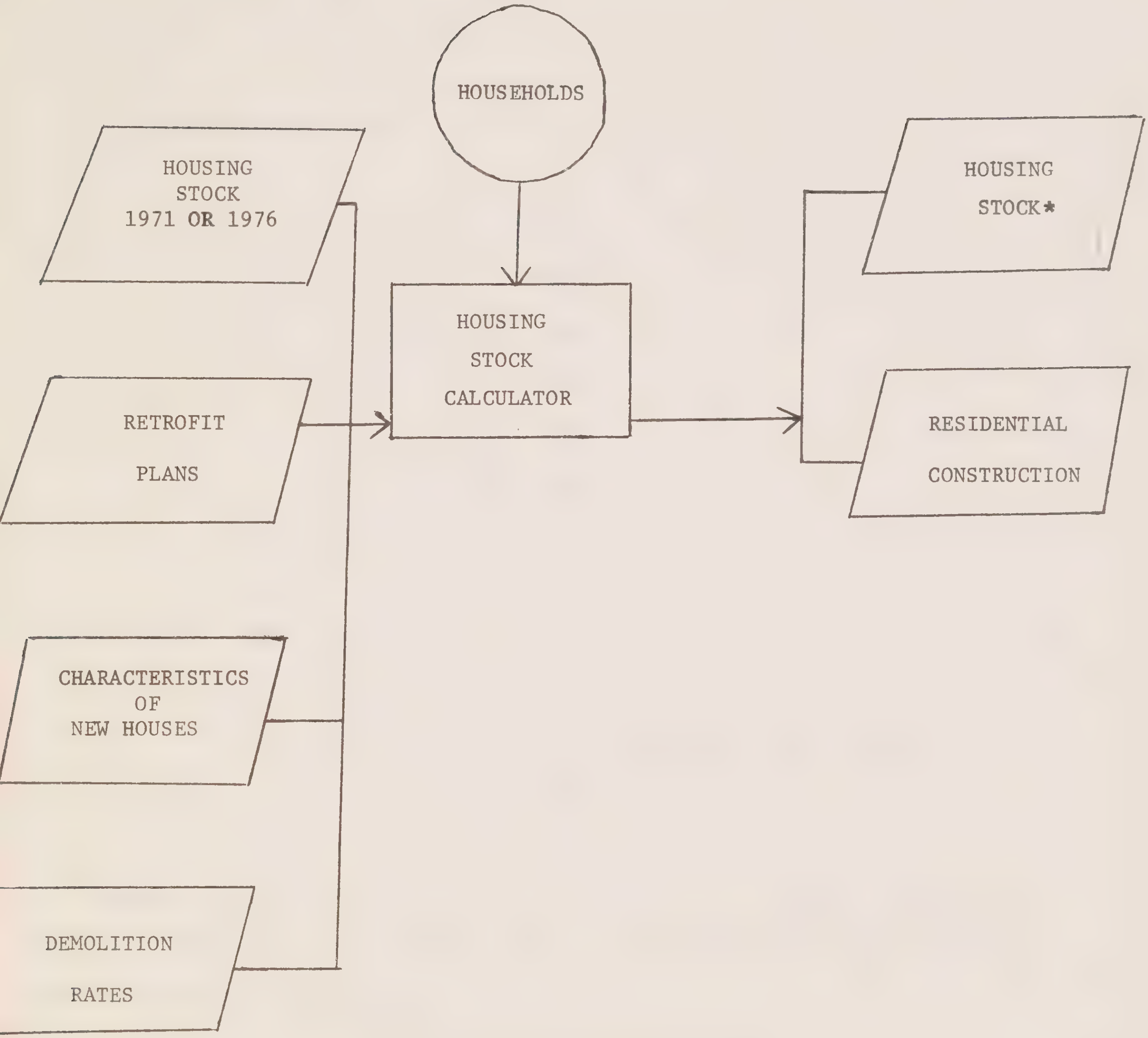
4 = built between 1951 and 1960

5 = built between 1961 and 1965

6 = built between 1966 and 1970

Figure 2.2

HOUSING STOCK FORMATION



* Housing stock is characterized by:

- type of house
- period of construction
- type of heating equipment
- thermal characteristics

7 = built in 1971

Equipment type

E= 1 = Water Oil (WO)

2 = Water Gas (WG)

3 = Water Solid (WS)

4 = Hot Air Oil (HO)

5 = Hot Air Gas (HG)

6 = Hot Air Solid (HS)

7 = Electricity (this includes both baseboard and furnace) (EE)

8 = Space Oil (SO)

9 = Space Gas (SG)

10= Space Solid (this represents wood stoves) (SS)

Water refers to hot water or steam, hot air means forced air with ducting, and space means point of use equipment such as oil space heated or wood stoves.

Thermal Characteristics

The thermal characteristics of the base stock are represented in the model by:

(1) a thermal archetype list;

and (2) a spreader array.

The archetype list contains number quadruples; the four numbers in each quadruple represent ceiling, wall, and basement insulation, and infiltration rate. The following tables relate the archetype codes to standard construction notation:

ceiling: (first number of quadruple)

1 = RO (no insulation exclusive of shell)

2 = R7

3 = R12

4 = R20

5 = R28

6 = R32

7 = R40

where R refers to the thermal resistance (Btu/hr ft^2 $^oF)^{-1}$ of the insulation added;

wall: (second number in quadruple)

1 = R0

2 = R5

3 = R7

4 = R1Ø

5 = R2Ø

basement: (third number in quadruple)

1 = RØ

2 = R3

3 = R5

4 = R7

5 = R1Ø

infiltration: (fourth number in quadruple)

1 = .75 (air changes per hour)

2 = .5

3 = .4

4 = .3

Note that these levels have physical meaning related to standard sizes of commercially available insulation components.

For each archetype (number quadruple) there is a set of percentages corresponding to the period of construction breakdown of the old stock. Each percentage specifies a proportion of the stock in some age category which is insulated according to its associated archetype.

The listing below is a sample archetype list and percentage distribution by period of construction:

Archetype List					Spreader Array						
					1920	1945	1950	1960	1965	1970	1971
K= 1	R0	R0	R0	0.5	10	10	2	2	1	0	0
2	R0	R0	R10	0.5	0	0	0	1	0	0	0
3	R0	R12	R0	0.5	6	6	5	5	1	2	0
4	R0	R12	R10	0.5	2	2	3	3	5	5	0
5	R7	R0	R0	0.5	7	7	3	3	1	1	0
6	R7	R0	R10	0.5	0	0	0	0	0	0	0
7	R7	R12	R0	0.5	5	5	5	5	2	2	0
8	R7	R12	R10	0.5	2	2	3	3	2	2	0
9	R10	R0	R0	0.5	14	14	5	5	1	1	0
10	R10	R0	R10	0.5	1	1	1	1	1	1	0
11	R12	R12	R0	0.5	16	16	19	19	11	11	13
12	R12	R12	R10	0.5	6	6	13	13	18	18	21
13	R20	R0	R0	0.3	5	5	2	2	0	0	0
14	R20	R0	R10	0.3	0	0	1	1	1	1	1
15	R20	R12	R0	0.3	11	11	13	13	10	10	12
16	R20	R12	R10	0.3	5	5	13	13	32	32	37
17	R28	R0	R0	0.3	2	2	0	0	0	0	0
18	R28	R0	R10	0.3	0	0	1	0	0	0	0
19	R28	R12	R0	0.3	4	4	4	4	3	3	3
20	R28	R12	R10	0.3	2	2	5	5	11	11	13
					100	100	100	100	100	100	100

The list is arranged in rough order of insulating efficiency with the least efficient archetypes first. List size is limited to 100 archetypes in the present version of the model.

Alterations to the level and composition of the base stock are effected through demolition and retrofit action.

Demolition

During each simulation period the model makes adjustments to the original stock levels by demolishing old stock and adding new. The user supplies estimates of demolition rates broken down by period of construction and type of dwelling.

Demolition can be regarded as part of the background scenario. However, simulation results can be very sensitive to the demolition rates. In most impact studies the demolition values are not crucial so long as they don't distort the stock distribution by either completely ignoring or greatly over stating natural attrition. For example, the assumption that no demolition occurred, or that all demolition rates are set to zero, would seriously distort the model's energy outputs. The older stock which was not destroyed has poor insulation levels; in fact, it is so much poorer than newer stock that the dwelling heat loss turns out to be a strongly non-linear function of dwelling age. Retrofit action occurring on this older stock would give the erroneous impression that large energy savings were being effected through retrofit.

We have derived a reasonable procedure for the estimation of demolition rates; inputs to the procedure are:

1) A constant demolition rate for all stock older than twenty years

2) A set of weighting factors for demolition of the different dwelling types

3) A set of weighting factors for the demolition of dwellings of the different periods of construction.

Retrofit

Alterations to the composition of the stock, after it has been aged, are achieved by permitting the user to apply two types of <u>retrofit action</u>: thermal retrofit and equipment retrofit.

Dwellings can either be thermally upgraded (thermal retrofit) through the addition of insulation and weather stripping or they can be equipped with energy conserving technologies (equipment retrofit) such as heat pumps, solar hybrid systems or district heating. These retrofit mechanisims allow the user to examine the long term implications of energy conservation strategies (thermal upgrading), fuel substitution strategies and improved technologies (equipment retrofit) on residential energy use over time. By long term a time horizon of between 20-50 years is understood during which the model simulates yearly updates to the

stock levels (new construction).

Such retrofit programs can be analyzed for the material and labour inputs required as well as for the final energy usage levels. At the present stage of development the material and labour inputs are not implemented into the household model.

Thermal Retrofit

The house components described in the archetype list can be improved proportionally during any simulation period by specifying transition arrays.

These square arrays are required for each simulation period; they refer to ceiling, wall, and basement insulation upgrade tendencies, and infiltration rate improvement tendency. The sizes of the arrays are defined by the range of their corresponding indices; that is, for the ceiling there are seven levels of insulation considered by the model, and for walls five levels and so on. The columns of the arrays stand for the "from" insulation level and the rows the "to" level when the houses are retrofitted. The array elements are percentages which show the proportion of the stock that changed insulation "from" the level corresponding to the column index "to" the level of the row index, where the row and column locate the percentage in the array. For example, to indicate no change at all a 100% is put on the main diagonal of the array, and to indicate a 15% change

from R0 to R7 in the ceiling a 85% is put in the upper left hand corner and a 15% is put underneath it.

For example:

Ceiling Transition Matrix

		From						
		R0	R7	R10	R12	R20	R28	R32
	R0	85	0	0	0	0	0	0
	R7	15	70	0	0	0	0	0
To	R10	0	30	100	0	0	0	0
	R12	0	0	0	100	0	0	0
	R20	0	0	0	0	100	0	0
	R28	0	0	0	0	0	100	0
	R32	0	0	0	0	0	0	100

The retrofit transition matrix is a very flexible device for exploring the effect of insulating the old stock. For instance, if the archetype tables' percentage distribution shows that a large percentage of the old stock of pre-1920 construction has a certain combination of insulation levels, the four transition matrices can be set up to retrofit any proportion of these houses

to any combination of new levels and/or old levels desired. Note that transition arrays are needed for each period in the simulation even if they do not cause a change. Note also that any transitions in insulation will cause changes in the distribution of the old stock over the archetype table and will very likely introduce new archetypes into the table as well. This means that transition arrays for one period will not have the same effect on energy use for the following period. If 50% of the (R0, R0, R0,.5) houses are retrofitted to (R20, R0, R0,.5) in period one then only half as many (R0, R0, R0,.5) houses remain in the old stock; thus, if the same retrofit arrays are applied in period two only a quarter of the original stock will be affected, and in period three an eighth, and so on. Meaningful transition arrays for any simulation period must take into account the effects of stock redistribution caused by the previous period's retrofitting.

Since it is very hard to guess the stock evolution by a succession of retrofit arrays, especially over fifteen to twenty periods, the model itself should be used experimentally along with a general set of retrofit objectives to discover a good time series of transitions. We are developing an array generator which would require only the energy savings desired and susceptibility levels by period of construction for retrofit.

Equipment Retrofit

Equipment installed in the housing stock is described in the model by the categories listed under E in 2.2. Since there are ten of these categories, changes from one equipment type to another can be shown by a 10 x 10 square matrix of proportions. Such an array should be provided for each dwelling type for each simulation period.

The rows (E dimension) stand for the equipment installed at the start of the current period while the columns stand for new equipment installed during the period. The equipment categories are extendable to accommodate new types of heating equipment such as solar hybrids, heat pumps etc. It should be noted that each period's retrofit actions can significantly change the status of the stock thus affecting the relevance of the subsequent period's retrofit arrays. The large data generation problem evidently facing the users of the model's retrofit facility has led us to design an heuristic array generator whose inputs would be energy savings desired, fuel use growth parameters, and dwelling type elasticity factors. Some hand correction of the resulting retrofit arrays will usually be necessary, but the data problems should be nearly eliminated.

New Construction

During each simulation period, demand for new construction is

calculated as a function of the net household formation, allowance for vacancies, and the replacement of dwellings which were demolished. The household formation component of the housing requirements is calculated using the population model.

Additions to the stock in each time period must be allocated by type of house, heating equipment type, and thermal characteristics.

Just as with the base year stock, new stock thermal characteristics are described by archetypes; thus the inputs would include:

- insulation archetypes for the new stock (number quadruples)
- percentages of the new houses assigned to each archetype.

The additions to the stock explained via this new construction mechanism will permit the investigation of conservation strategies pertaining to improved insulation standards and the introduction of renewable energy technologies (solar and their hybrids) and new technologies such as the heat pump. Again the end-use energy requirements and material and labour inputs can be analysed in order to evaluate their impact on the Canadian production system.

2.3 Space Conditioning Block

The space conditioning calculations are mostly based on a 'technical fix' approach and on 'useful energy' demand; that is demand for final heat and work to heat buildings and power equipment. This approach is relevant for evaluating the technical advantages associated with conservation and renewable energy technology strategies. These strategies can be evaluated, particularly in the long term, in the light of direct energy consumption and material and labour cost of their implementation.

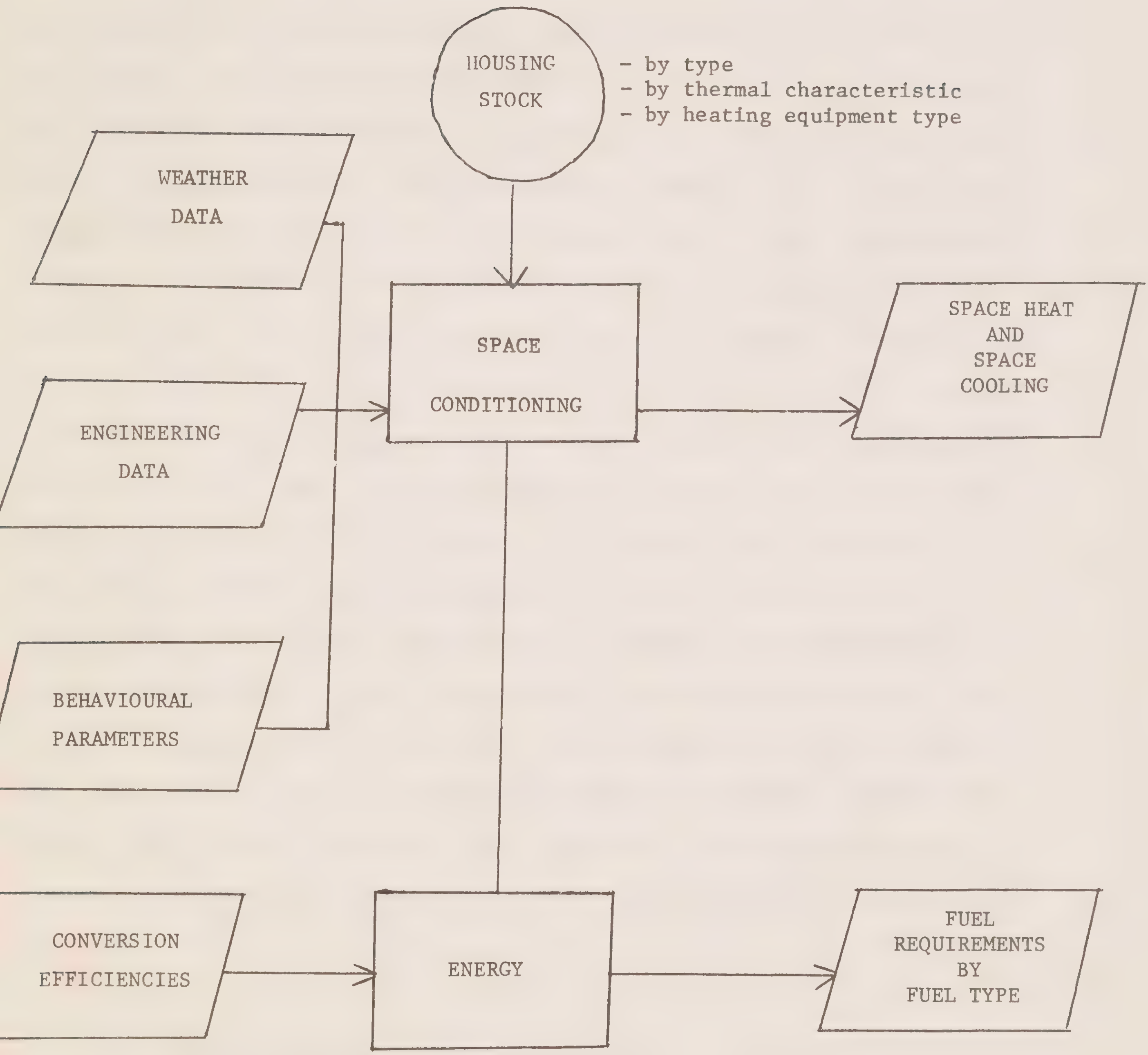
The space heating and cooling end uses are most amenable to this 'useful energy' demand approach. The structure of the 'household model' is largely governed by the requirements of this highly disaggregated approach in the technical analysis of 'useful energy' demand formation.

In its most elementary form the total 'useful energy' requirements for space heating/cooling is the product of the total number of dwellings by a per dwelling 'useful energy' requirement for space heating. The disaggregation of the housing stock reflects the principal explanatory variables which determine the heating/cooling loads.

As mentioned earlier this paper is concerned with the space heating end use only. A brief description of the technique used is therefore justified. The space heating energy use is

Figure 2.3

SPACE HEATING AND COOLING



estimated using the 'equivalent degree day method'. The 'degree day' method for calculating the annual heating requirements for residential dwellings is well known (4). However, the 'degree day' method, when applied to modern, well insulated dwellings with low infiltration rates generally results in a significant over-prediciton of the actual heating load. The conventional 'degree day' method uses an arbitrary balance temperature of 65°F (18.3°C) and the degree days based on this balance temperature are available for most localities. The choice of 65°F as the balance temperature does account for fortuitous heat gains (solar gain and 'wild heat' from appliances) since the design inside temperature is 70-72°F. However, it appears that the use of an arbitrary fixed balance temperature is not adequate in representing the large variation of thermal characteristics of the housing stock. Thus, to provide the required accuracy in a large disaggregated housing stock model approach, such as used in the 'Household Model', a modifed degree day method (equivalent degree day method) is used which permits the calculation of an appropriate balance temperature which is an explicit function of the:

(1) thermal archetypes of the stock;
(2) solar heat gain;
and (3) the average 'wild heat' gain.

For a more complete description of the justification of this technique see reference (5).

Initially some intermediate data are calculated which we call the thermal characteristics data base or the overall heat transfer coefficient of the housing stock. For each type of dwelling and thermal archetype, the overall heat transfer coefficient is calculated by considering two main transfers of heat; that through the fabric of the building (fabric heat transfer), and that due to the infiltration of air (infiltration heat transfer). As stated above a thermal archetype is defined as a configuration of ceiling, wall, basement wall insulation levels and infiltration index. The overall heat transfer coefficient is calculated by considering each element of the dwelling. These would include the ceiling, external wall, basement wall above and below grade, windows and doors. Once the overall heat transfer coefficient has been calculated for a particular thermal archetype set it is simply used as a data base or 'look up table' and is not recalculated each projection period.

In summary, the exogenously defined heat transfer characteristics data base together with other exogenously defined variables such as weather data and behavioural parameters (thermostat setting) will determine the per dwelling 'useful energy' demand for space heating. N.R.C. hourly weather data records of the ambient temperature and solar heat gain factors were used in the 'equivalent degree day' method.

The total 'useful energy' demand is the product of the number

of dwellings and the per dwelling 'useful energy' demand.

Finally, the total 'delivered energy' requirements by fuel type is calculated by introducing seasonal efficiencies of the heating system. Improvement in the efficiency of delivering the 'useful energy' can thus be explicitly represented to reflect further energy conservation strategies.

2.4 Construction Materials Block

At the present stage of development, the construction materials model has not been implemented. It is anticipated that the formalized approach developed by Matuszewski et al (3) will be adapted for this purpose. The data requirements for this model would be in the form of quantity survey data for each of the different housing types represented in the household model. The materials and labour formation model will be driven, to a large extent, by the housing formation model, in that the demand for materials and labour is formed as a consequence of new construction activity and retrofit action.

2.5 Appliance Stock and Utilization Block

Appliance Energy Use

Appliances constitute the remaining set of household energy end use devices (e.g. stoves, lighting, fridges, etc.). It is

Figure 2.4

CONSTRUCTION MATERIALS BLOCK

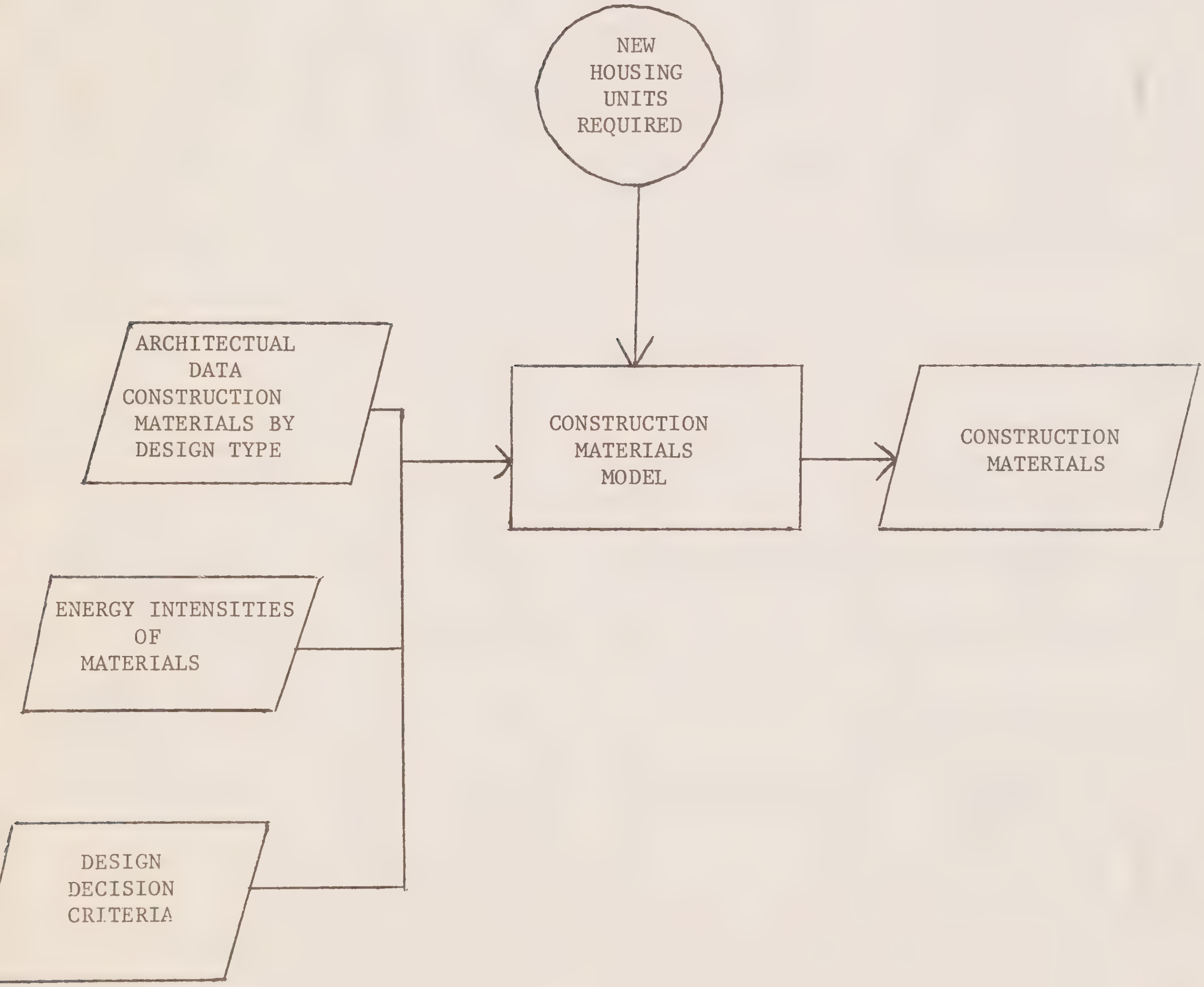
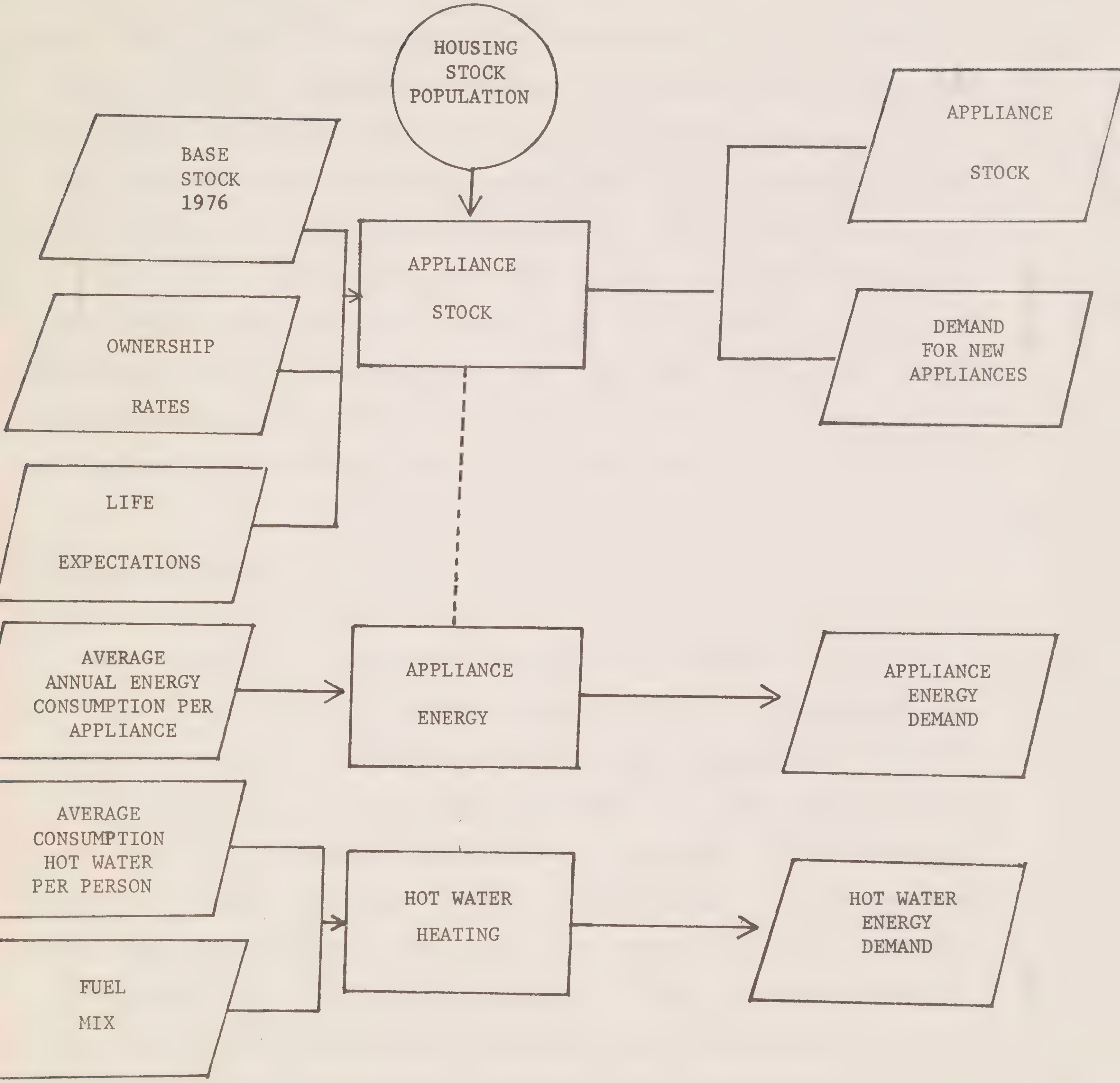


Figure 2.5

APPLIANCE STOCK AND ENERGY DEMAND



well known that few data are available on the specific requirements for cooking and the use of lighting and appliances, which would be suitable for making an evaluation similar to the space conditioning and water heating end use. Consequently, the approach used in calculating the useful energy requirements of occupants for appliance use, is based on utilities' past consumption data and the current ownership level of various appliance types. A version of the appliance utilization model has been implemented and is described in detail as a component of the Consumer Expenditure Model by F. Borde (6).

Water Heating Use

The 'useful energy' requirements of households for water heating is calculated by first estimating the average quantity of hot water used per day per person and then determining how much 'useful energy' is required to raise it from cold inlet temperature to a desired temperature. Knowledge of the average number of persons per household and the number of households completes the calculation of the total 'useful energy' requirements for hot water heating. The delivered energy requirements by fuel type can then be calculated by the introduction of fuel specific equipment efficiencies.

3. Data

3.1 Base Stock of Dwellings

There are two main sources of data for the base stock of dwellings: the 1971 population census and the annual Household Facilities Survey (HFS).

From the 1971 census the housing stock can be stratified by type of house, period of construction, and type of heating equipment in accordance with the categories for each characteristic presented in section 2 above. These data are available at the national, provincial, and municipality level.

The HFS stratifies the housing stock according to similar categories as the census. Because the HFS is an annual survey, more current data are available; however, because it is a sample survey, it will support provincial estimates only.

Data on the thermal characteristics of existing dwellings are not available in any comprehensive way. The insulation archetypes and spreading percentages used to define the old stock thermal qualities were estimated from data provided by the ENERSAVE program. The estimations involved expanding ENERSAVE period of construction ranges from three to seven and converting insulation levels to standard "R" value quantitiees. Since the ENERSAVE survey was conducted in the smaller urban areas the

archetype table that derives from it probably does not include some typical Toronto housing types.

For the purpose of the study the 1971 census source was used to provide estimates of the base stock of dwellings in Ontario.

3.2 Weather Data

Weather data in the form of average hourly temperature over full calendar years for selected locations throughout Canada are available from the National Research Council. The weather data appropriate for user defined regions: - Canada as a whole, individual provinces, or individual municipalities will be computed as weighted combinations of the data for NRC locations.

For the purpose of the simulations presented in this paper, the Ottawa region tape was used.

Since Ottawa has 8700 degree-days and Toronto only 6800 degree-days (65^{0}F base) energy results from the model will be biased upward somewhat.

3.3 Exogenous Variables

The exogenous variables that must be provided in order to run the housing stock formation block and the space heat part of the space conditioning block include the following time series:

1. Demolition impact proportions (matrices).
2. Insulation retrofit parameters (matrices).
3. Equipment retrofit parameters (matrices).
4. New housing totals (scalars).
5. Vacancy rates (scalars).
6. New housing proportions by type (vectors).
7. New housing proportions by heating equipment (matrices).
8. New housing insulajtion archetypes and proportions (vectors).

4. Simulation Results

For the purpose of demonstrating the flexibility of the model and of investigating the sensitivity of energy demand to thermal retrofitting, three scenarios were developed.

1. Medium scale retrofitting, such as might occur in the natural course of events without external stimulus.
2. No retrofitting, that is with the inputs turned off in order to show the background movements of the energy consumption outputs.
3. Low energy consumption through high levels of thermal retrofitting.

The model runs have a time step of five years and run from 1972 through 2001. In the first period, 1972-1976, currently available statistics were used to construct the inputs, and

current energy statistics were available to calibrate the calculations. For subsequent periods the time series are all hypothetical impacts which create the energy results as an effect.

The Calibration Period 1972-1976

The 1976 census does not provide a breakdown of housing by period of construction or installed heating equipment. Moreover, there are differences between the 1971 and the 1976 census in definition of housing type. Because of these difficulties with the 1976 census the present examples treat the 1972-1976 period as the first simulation period. The sources of the time series inputs for 1972-1976, in the order that they are listed above in 3.3 are:

1. Overall demolition count was obtained by subtracting the 1971 census total from the 1976 census total and then subtracting that result from the CMHC housing completions. This overall demolition count was disaggregated by housing type and period of construction by assuming very heavy weighting towards older houses and single detached houses.
2. The insulation retrofit were set up to reflect current levels of retrofit activity.
3. Equipment retrofit was also set up to reflect current activity with a distinct movement towards gas and away

from oil heating.

4. CMHC housing completion figures provided the aggregate new housing count.
5. The vacancy rate was assumed to be the same as that used by the CMHC Housing Requirements Model for Ontario.
6. The CMHC completions data give new housing proportions by type.
7. The labor force survey extension from STC (HFE Survey) provides a breakdown of the stock to 1975 by furnace type, albeit based on a small sample; this was used to set up this matrix.
8. The new housing insulation archetypes were determined from building standards for the last five years.

With the 1972-1976 inputs set up this way the energy results are sufficiently close to the Statistics Canada Energy Supply and Demand figures to indicate that the calculations are operating properly.

The Simulation Period 1977-2000

The CMHC household requirements model generates new household construction counts for each year from 1977 through 2000. The example runs discussed below input these counts aggregated into five year periods. The corresponding demolition counts, also an output of the CMHC model, were used as check totals for the time series of demolition percentage arrays. The vacancy rates were

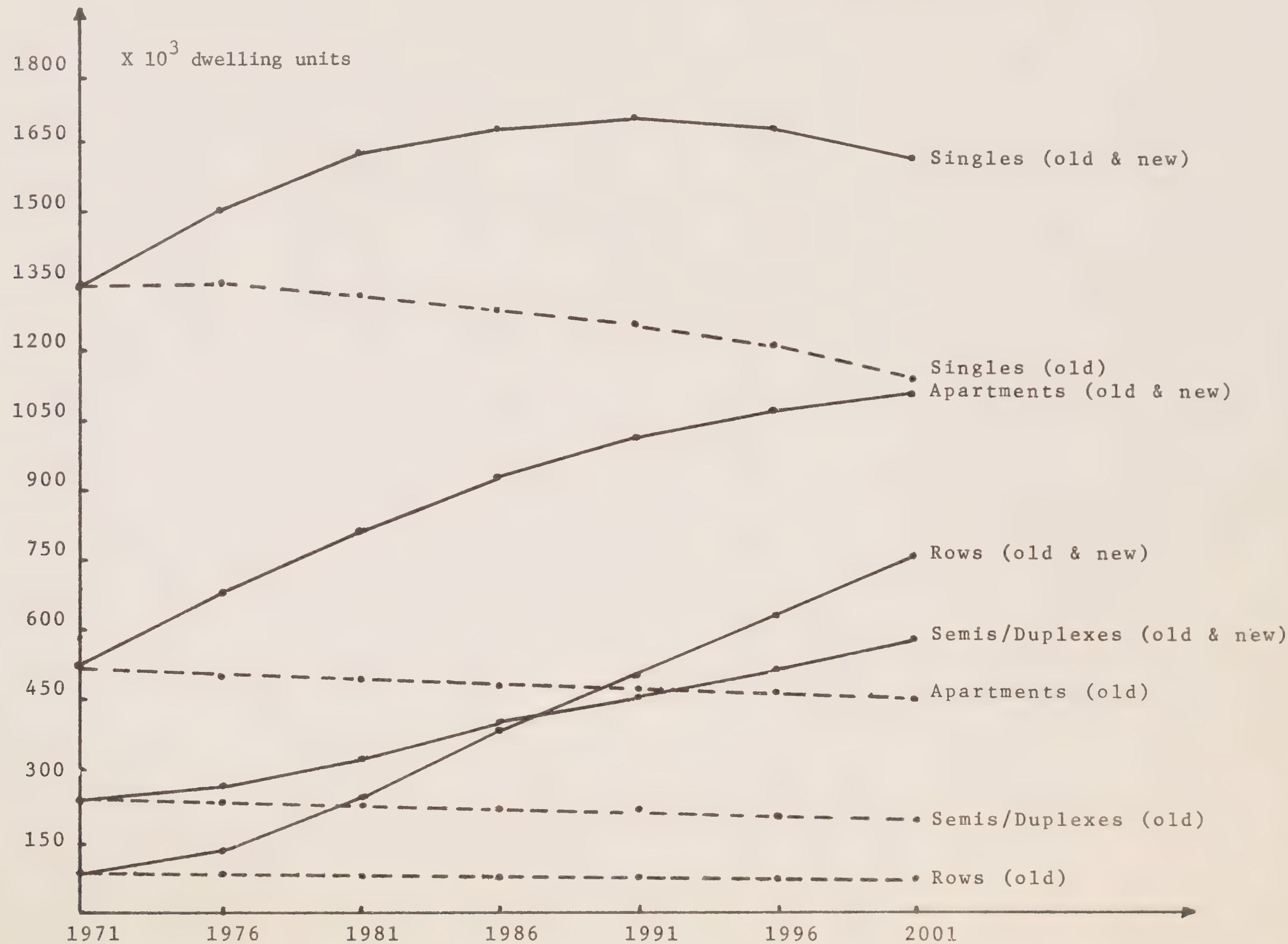


Figure 4.01 Evolution of Old and New Construction

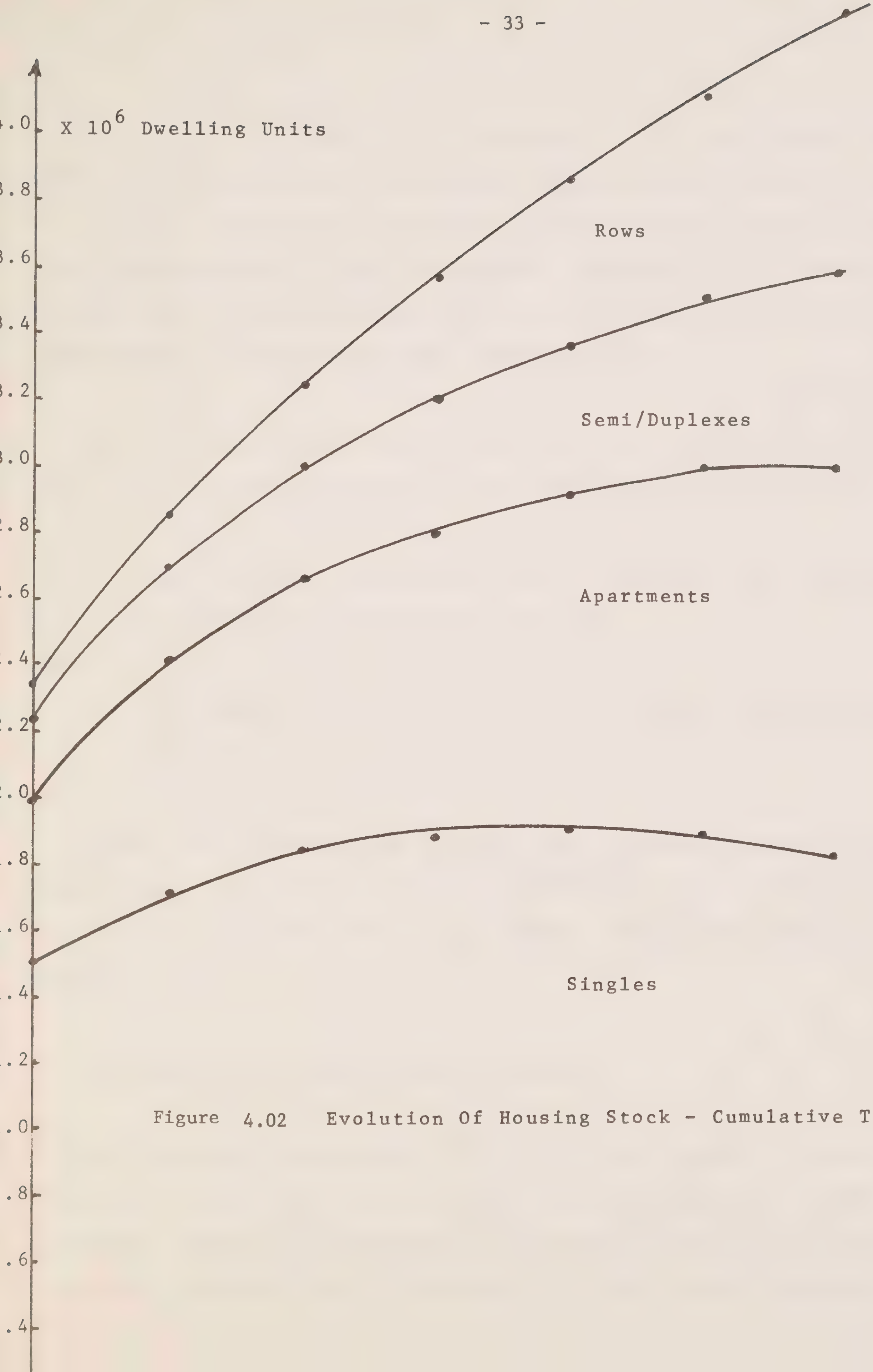


Figure 4.02 Evolution Of Housing Stock - Cumulative Totals

assumed to be the same for all periods. The distribution of dwelling type and heating equipment amongst the new stock during the forecast periods was estimated by observing the patterns and relationships found in the 1971 census, the labor-force extension survey, and the housing completions data for 1971-1976, and then hypothesizing linear trends from these sources.

Figure 4.01 graphs stock levels by simulation period and gives a notion of the stock evolution from 1971 to 2000 showing:

1. The effect of demolition rates on the old stock (dotted lines) shown for each housing type;

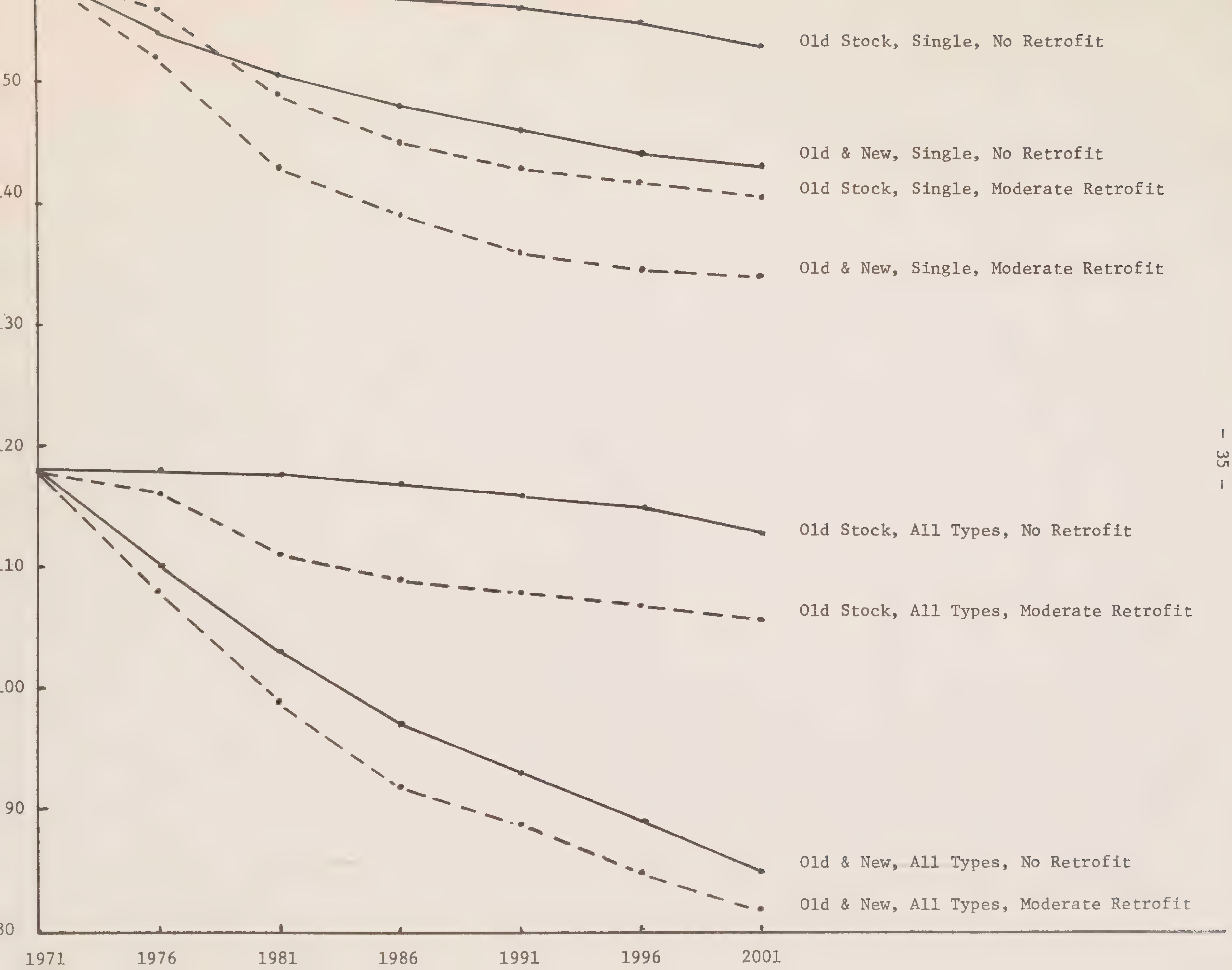
and

2. The comparative growth of the four housing types (solid lines).

Figure 4.02 combines the old and the new stock together and graphs them cumulatively showing stratification of the stock by type of dwelling and total stock growth during the simulation period.

4.1 A Retrofit Scenario of Medium Intensity

The retrofit parameters used in this example affected insulation in the ceiling only; but, the time series of retrofit parameters gradually increased the probability that the poorly insulated ceilings would be upgraded to much higher insulation



Old Stock, Single, No Retrofit
Old & New, Single, No Retrofit
Old Stock, Single, Moderate Retrofit
Old & New, Single, Moderate Retrofit
Old Stock, All Types, No Retrofit
Old Stock, All Types, Moderate Retrofit
Old & New, All Types, No Retrofit
Old & New, All Types, Moderate Retrofit
100
90
1971
1976
1981
1986
1991
1996
2001

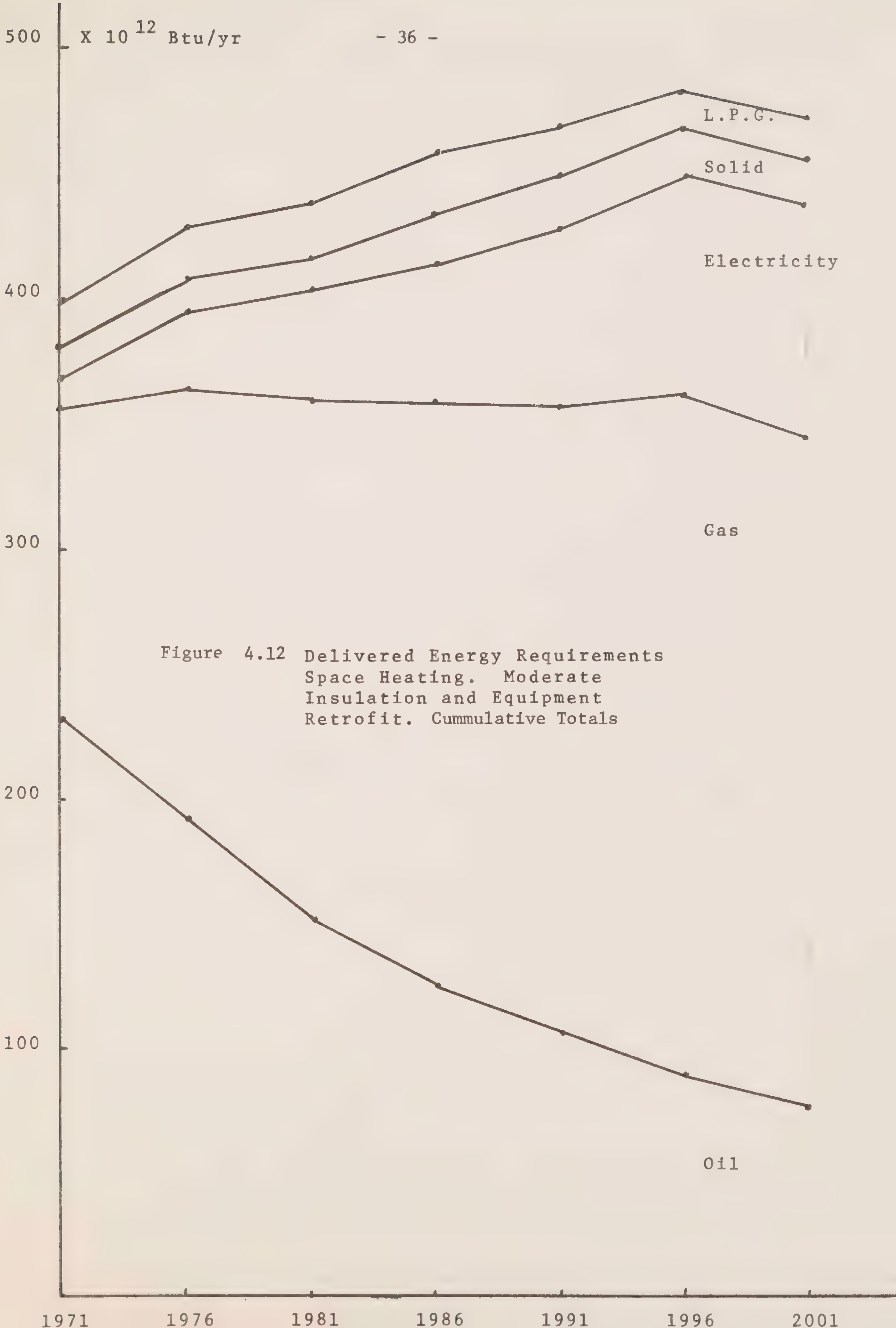
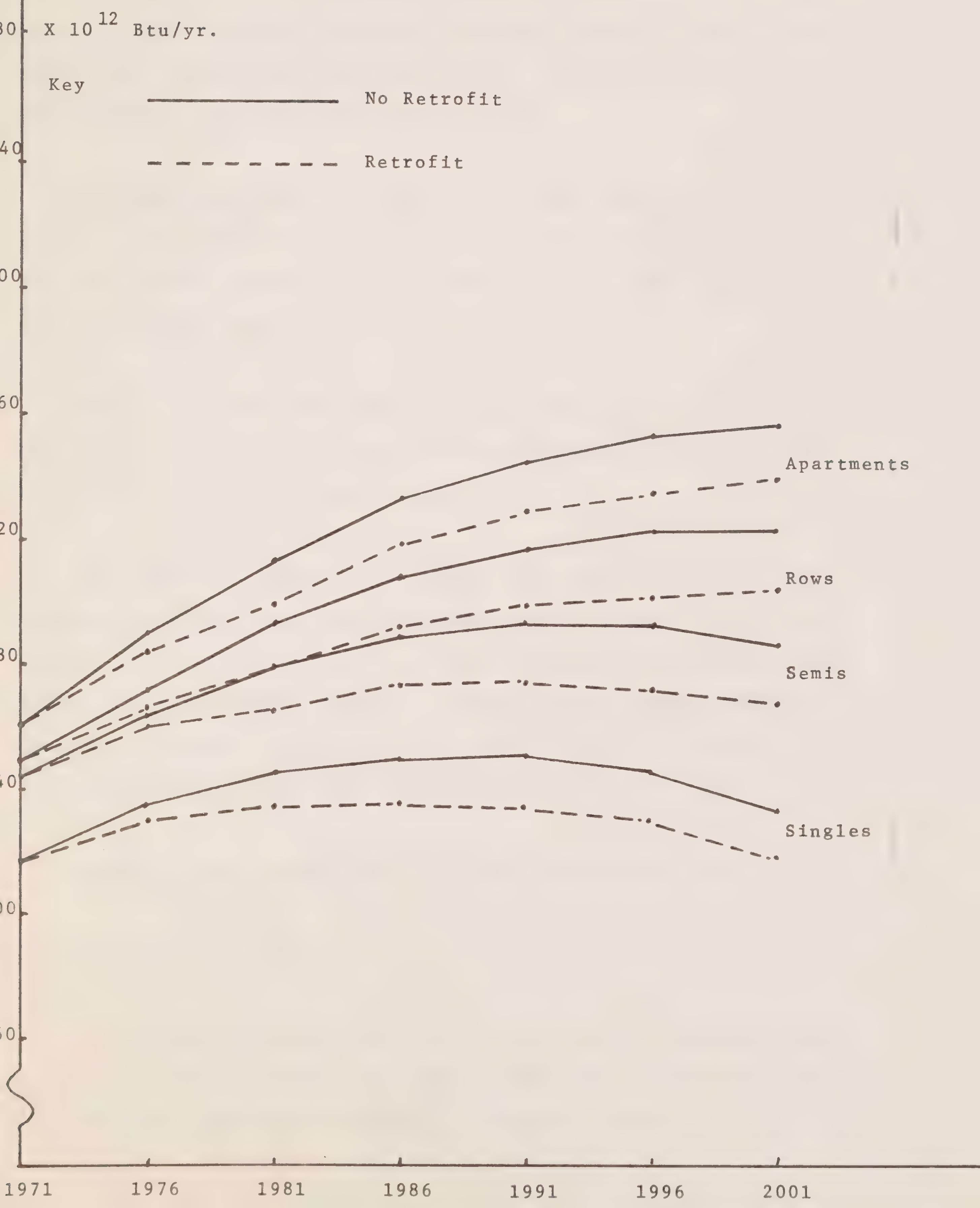


Figure 4.12 Delivered Energy Requirements Space Heating. Moderate Insulation and Equipment Retrofit. Cummulative Totals

Figure 4.13 Useful Energy Requirements - Space Heating
Moderate Insulation Retrofit.
Cummulative Totals



levels. The equipment retrofit parameters were set up to cause fuel usage which would conform to the trend indicated by the Ontario Hydro electrical inspection reports.

The graph in figure 4.11 shows the change which occurs in the useful energy requirements for the average house as a result of the insulation retrofit and the demolition of the older, less well insulated houses.

Graph 4.11 also shows the corresponding input measures for the no-retrofit scenario such that the efficiency changes in the average dwelling can be easily seen.

The graph in figure 4.12 shows the cumulative fuel usage changes resulting from the equipment retrofitting of the old stock and the distribution of equipment installed in houses built during the simulation. Graph 4.12 shows useful energy demand by type of dwelling as it evolves over time as a result of insulation retrofitting and new stock additions.

Graph 4.13 also shows levels for the no-retrofit scenario.

4.2 A No-retrofit Scenario

These results indicate the role of the retrofit programs used in the previous example. The input levels are shown in figure 4.11 and the useful energy demand is shown in figure 4.12.

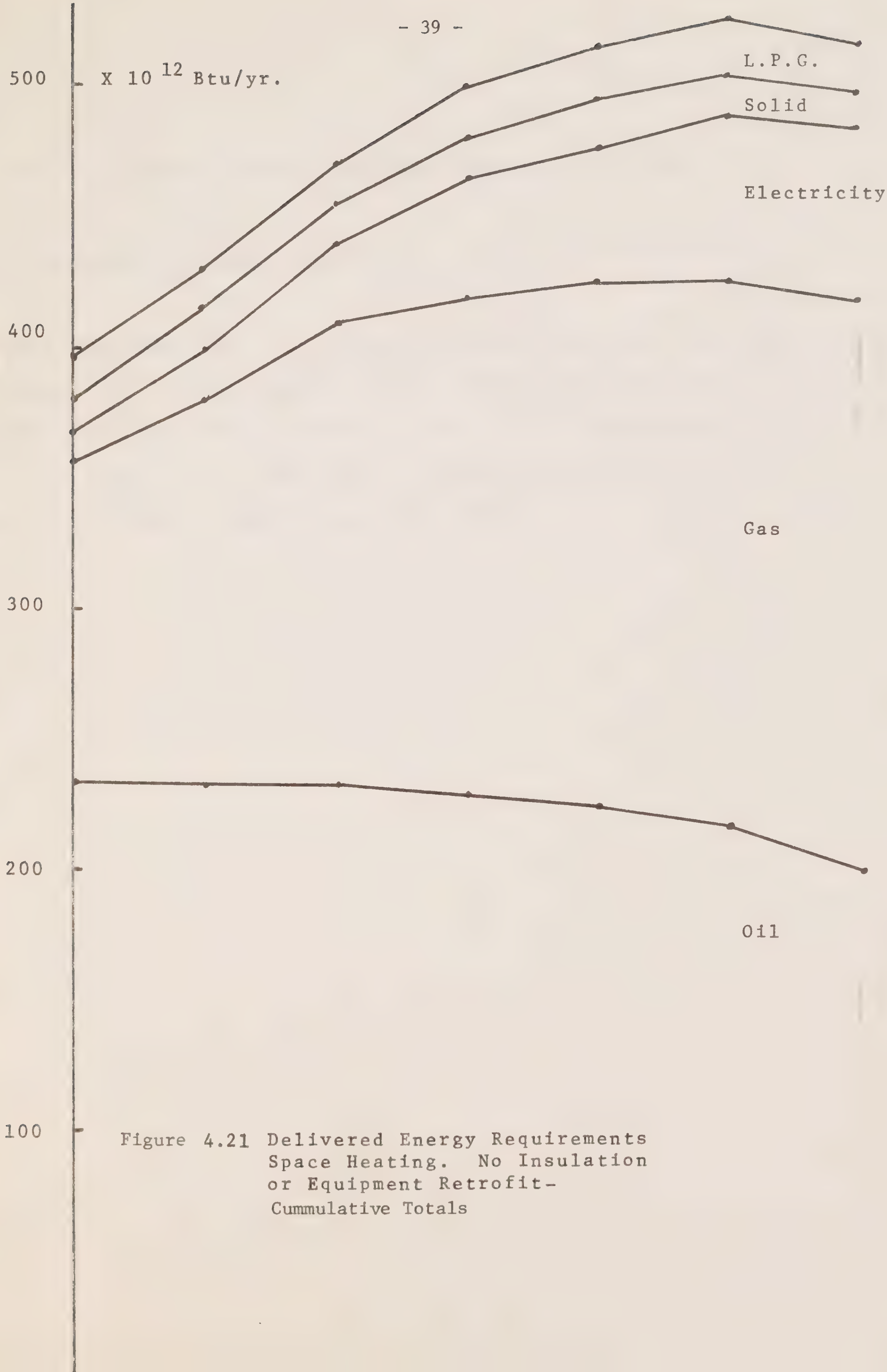


Figure 4.21 Delivered Energy Requirements Space Heating. No Insulation or Equipment Retrofit- Cummulative Totals

Delivered energy results are shown separately in 4.21.

4.3 A Low Energy Retrofit Program

This example has far more intensive thermal retrofit activity. The walls, bsement, and the infiltration rate were all upgraded to help lower the average useful energy requirements per dwelling (graph 4.31). The output graphs (figures 4.32 and 4.33) show a significantly lower energy consumption.

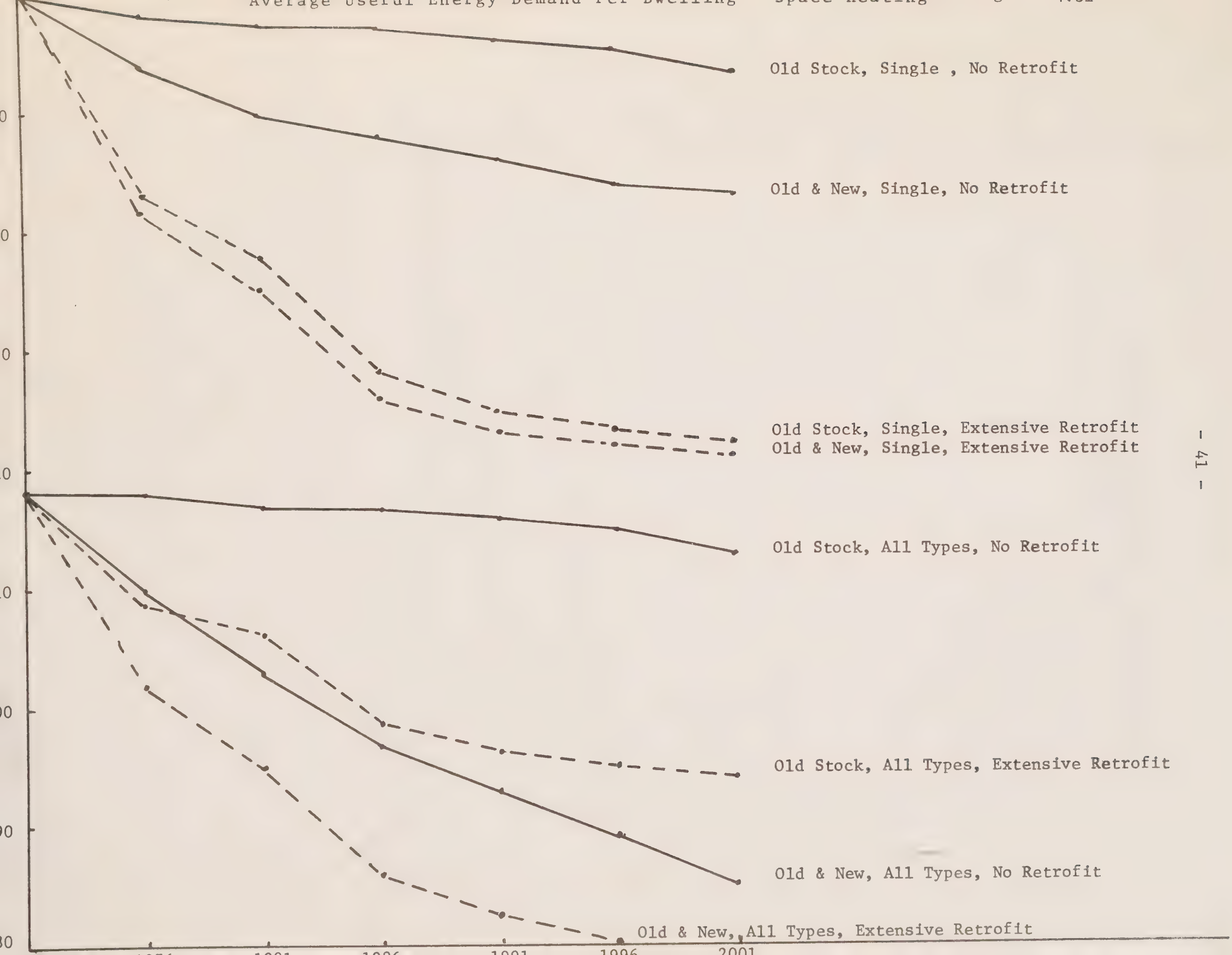

Old Stock, Single , No Retrofit
Old & New, Single, No Retrofit
Old Stock, Single, Extensive Retrofit
Old & New, Single, Extensive Retrofit
Old Stock, All Types, No Retrofit
Old Stock, All Types, Extensive Retrofit
Old & New, All Types, No Retrofit
Old & New, All Types, Extensive Retrofit

Figure 4.32

Useful Energy Requirements - Space Heating
Extensive Insulation Retrofit
Cummulative Totals

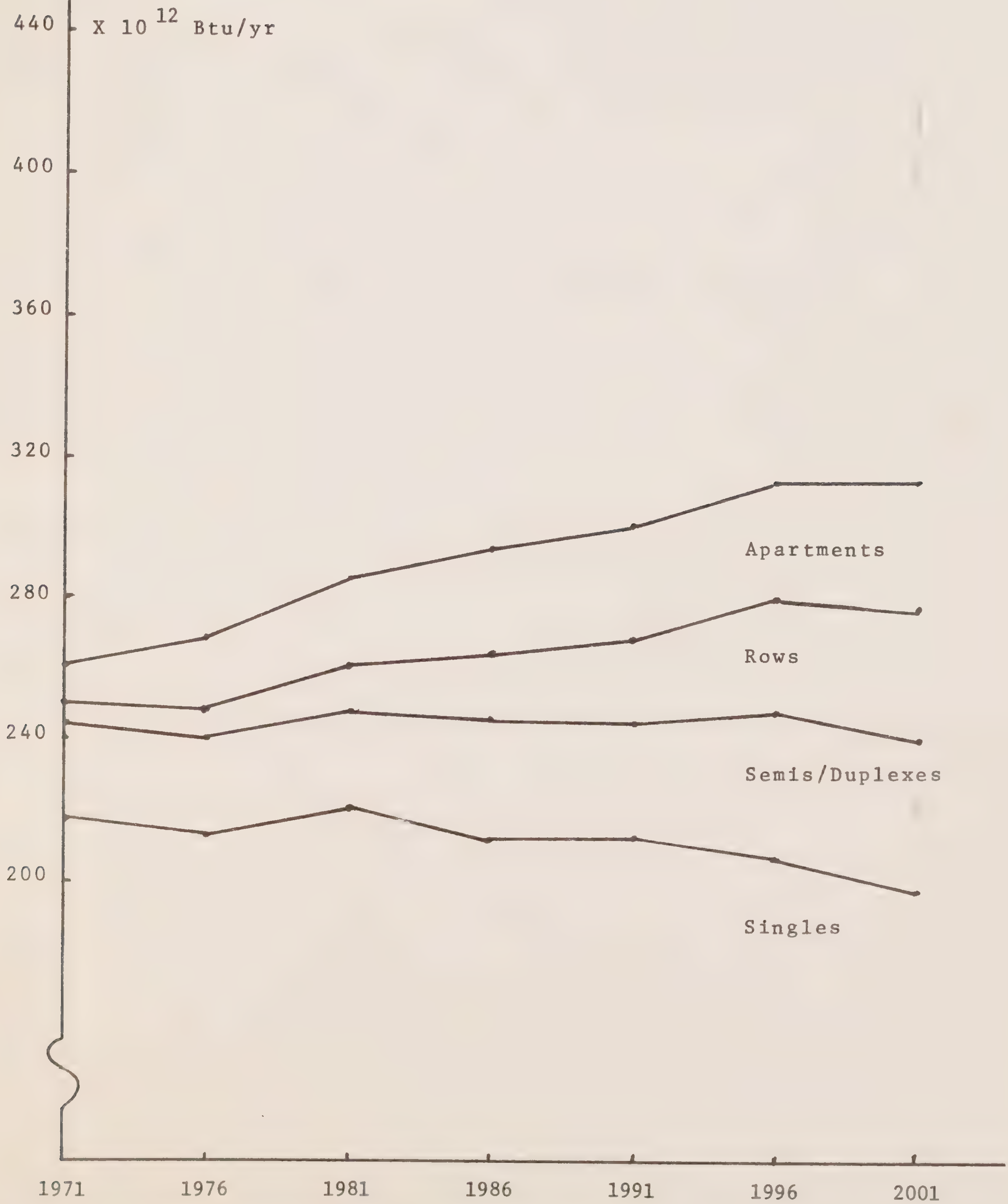
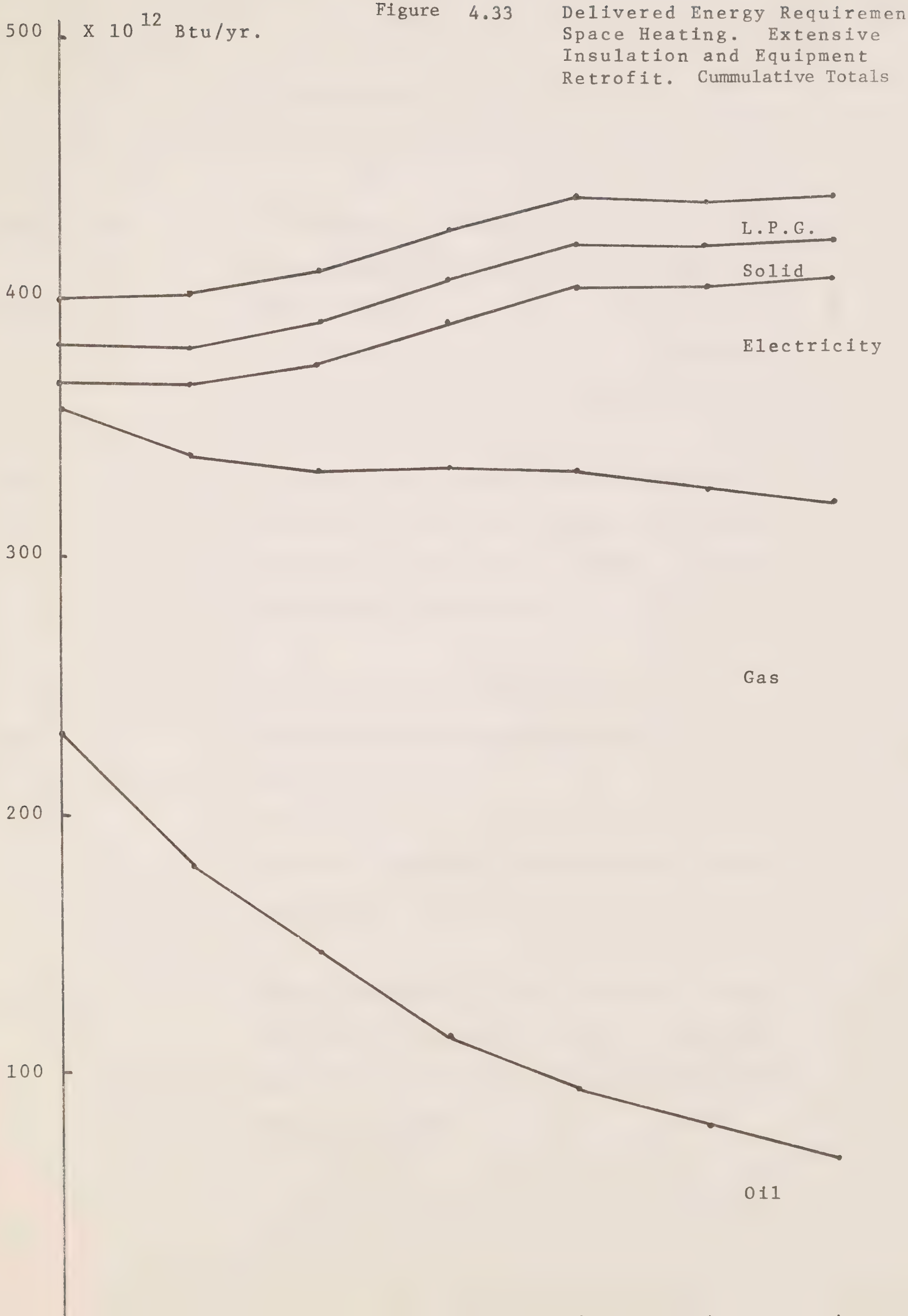


Figure 4.33 Delivered Energy Requirements Space Heating. Extensive Insulation and Equipment Retrofit. Cummulative Totals



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